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Laser Gyro Balancer Summary Report
Contract Number NAS8-20585

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1.0 Introduction

The purpose of this project was to develop a laser system capable of dynamically balancing gyro rotors, and statically balancing accelerometers.

The particular design objectives were the following:

Workpiece Rotational Speed Range:	2,000 - 24,000rpm
Pulse Width:	Mode 1 - 500 microseconds Mode 2 - 40 microseconds
Pulse Energy:	Mode 1 - 25 joules Mode 2 - 10 joules
Focused Spot Size:	1mm
Pulse Synchronization:	Panel meter to enable operator to set laser beam at any point on the rotor.
Typical Metal Removal Performance:	Mode 1 - 0-2.0 milligrams Mode 2 - 0-0.5 milligrams
Rotor Size:	Up to 5 cm diameter, limited to capability of dynamic balancer.
Compatibility:	Compatible with Schenck & Microbalancing equipment.

The laser gyro balancer as supplied to NASA MSFC is comprised of a power supply, laser head, focusing cone, water cooler and remote control console. For particulars on operation of the system, refer to instruction manual.

2.0 Criteria for Selection of Laser System

In order to meet the design objectives and provide a system that was both reliable and compact, the hair-trigger or piggy-back mode of laser operation was selected.

The criteria underlying this selection were the following:

A. System to be as small as practical to adapt to cleaning room type installation.

B. Pulse width and occurrence to provide timing accuracy of 5° at a workpiece speed of 24,000rpm maximum.

C. Sufficient laser output energy to remove the required amount of material from different metals.

D. Laser system to be adaptable with existing types of balancing equipment.

3.0 Design Principles

3.1 Energy Requirement Analysis

A. Correlation was obtained between material removal and laser output energy for various metals. The metals tested were Elkonite 4069-C$_3^2$ Monel KR, stainless steel, and brass. It was determined that at least 10 joules of output was required to meet the specifications. In order to meet the pulse width requirement the piggy-back or hair-trigger mode of laser operation was chosen. In this method the laser is first brought to threshold with one energy storage bank, and then at a predetermined instant enough energy is supplied by a second bank to provide useful output. With a 9/16 x 4" laser ruby rod, threshold is reached at an energy of approximately 2400 joules. Therefore to supply this energy with a 400µf storage capacitor requires a voltage;

$$V=\sqrt{\frac{2\,E}{C}} = \sqrt{\frac{2(2400)}{400\times10^{-6}}} = 3.45\text{KV}$$

In the actual system the optimum value for this voltage is 3.2 KV. Now, in order to provide at least 10 joules of useful output implies that we must supply $\frac{10}{\eta}$ joules of input with the second energy storage bank, where η is the laser efficiency. For the particular flash lamp and laser head geometry, η is typically 0.75%.

To provide 10 joules of output therefore requires

$$\frac{1000}{.75} = 1333 \text{ joules of input.}$$

To store this energy with a 14µf capacitor bank requires a voltage of

$$V=\sqrt{\frac{2\,E}{C}} = \sqrt{\frac{2(1333)}{14\times10^{-6}}} = 13.8\text{KV}$$

In the actual system a capability of approximately 14.8KV is provided.

3.2 Optical Requirement Analysis

To provide power densities great enough to meet the metal removal specifications required a focused laser output of minimum diameter. The focused laser output or spot diameter, d, is calculated to a first approximation by d=fθ, where f is the focal length of the lens at ruby wavelength (6943Å), and θ is the beam divergence of the laser ruby rod in milliradians. For a given beam divergence, spot diameter is decreased as the focal length is decreased. But there is a practical limit to which the focal length can be decreased before the effects of spherical aberration set in.

Spot diameter can also be decreased as the beam divergence is decreased. Beam divergences of the order of 3 milliradians are readily achieved when a laser cavity of 17" or longer and external mirrors are utilized. To meet the size requirement of this laser system, required that dielectric reflectors be thin-film deposited on the faces of the ruby rod. Unfortunately this increases the beam divergence to approximately 10 milliradians. Utilizing a 2" focal length lens, in the actual system, yields a spot diameter of $2(10^{-2}) = .02"$ or 0.5mm which is well within specifications.

3.3 Electronics Requirement Analysis

To implement the piggy-back or hair-trigger laser system required the following basic circuitry:

A. A high voltage power supply to bring the laser to threshold.

B. A second high voltage power supply to enable the laser to exceed threshold and supply output energy.

C. Timing and triggering circuitry to commutate the two high voltage supplies.

D. Logic circuitry to perform charging, dumping and firing functions.

In addition, in order to time the occurrence of the laser pulse on the workpiece periphery, required delay circuitry designed to accommodate a workpiece speed of 2000 to 24000rpm. This range of speed corresponds to periods of 30 and 2.5 milliseconds respectively. In order to resolve a 5° angle at the highest speed required a delay of $\frac{5}{360}$ (2.5 milliseconds) = 35μsec. Accordingly, the range of delay made available was 10μsec. to 100msec.

Items A through D inclusive are located in the Power Supply Console.

Timing circuitry and logic to remotely operate the system, is provided at the Remote Control unit.

4.0 Technical Findings

The following chart summarizes the weight change of several different metals after laser irradiation.

Material	Metal Removal Rate (mg/pulse) Coarse Mode Workpiece speed, 2000rpm	Metal Removal Rate (mg/pulse) Fine Mode Workpiece speed, 24000rpm
Stainless Steel	3.0	0.5
Monel KR	2.0	0.5
Elkonite	3.0	1.0
Brass	2.2	0.6

In the coarse mode of operation the 5KV bank was charged to 4.8KV. In the fine mode of operation the 15KV bank was charged to 14.9KV. For a correlation between 15KV bank voltage and output evergy refer to figure 1. For a correlation between 15KV bank voltage input energy and output energy refer to figure 2. Figures 3 and 4 are oscillograms of the actual laser output pulses in the coarse and fine modes of operation respectively. Figure 5 displays the sequence necessary to produce a piggy-back laser pulse.

Photographs of the actual plume resulting from metal vaporization indicated that normal incidence of the laser beam to the work-piece resulted in the greatest amount of back splatter. Angles of incidence approaching tangency to the workpiece produced the least amount of back splatter. For any particular metal, an optimum angle of incidence should be determined experimentally.

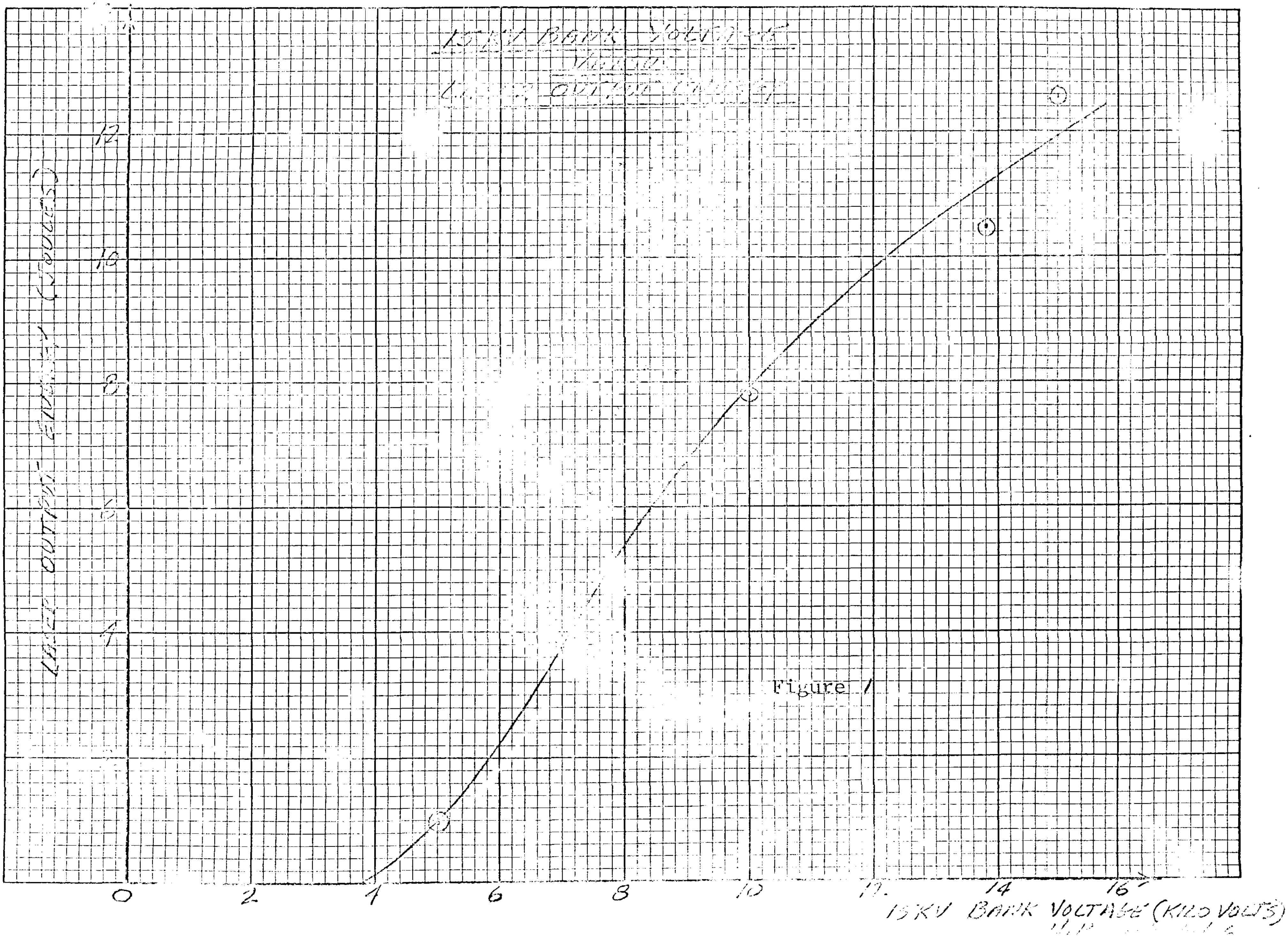

LASER OUTPUT ENERGY (JOULES)
12
10
8
6
4
0
2
4
6
8
10
12
14
16
15KV BANK VOLTAGE (KILO VOLTS)

Figure 1

10 X 10 TO THE INCH 46 0703
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

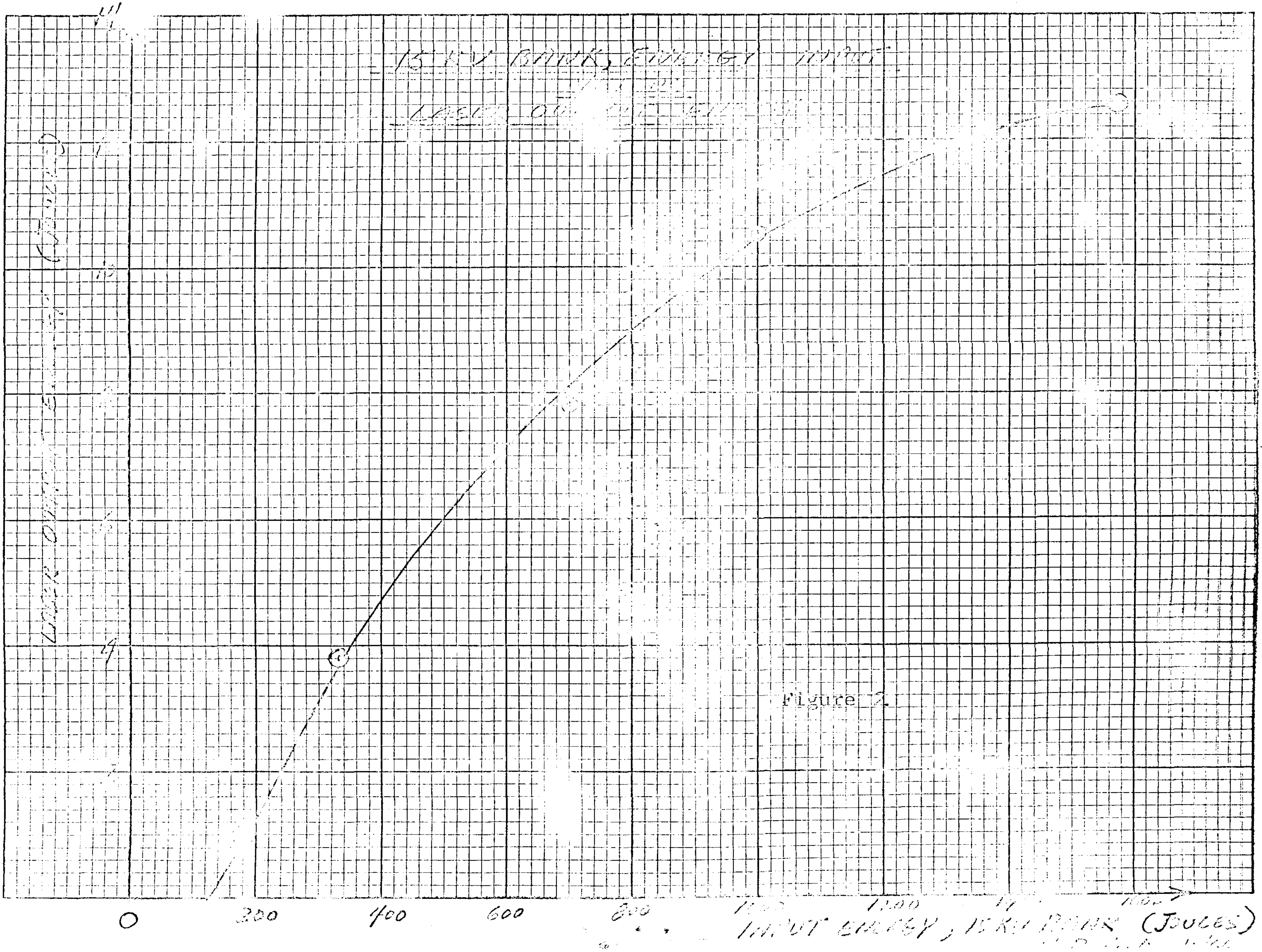
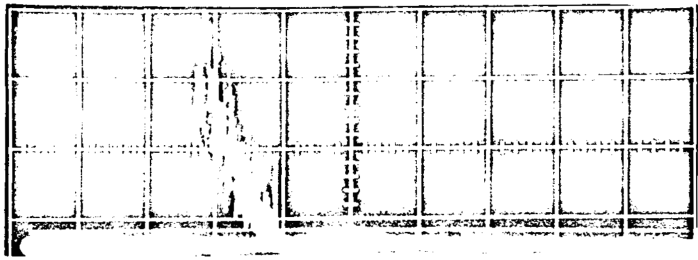
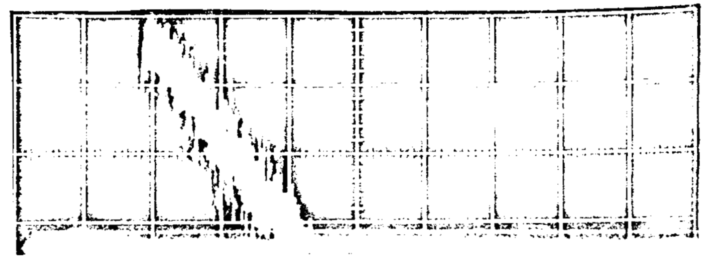


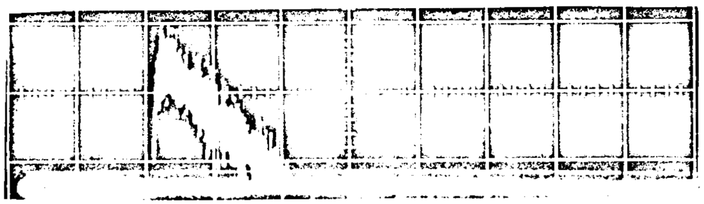
Figure 2



5KV Bank Voltage set to 3.4KV
Vert. 0.5V/cm
Horiz. 0.5msec/cm



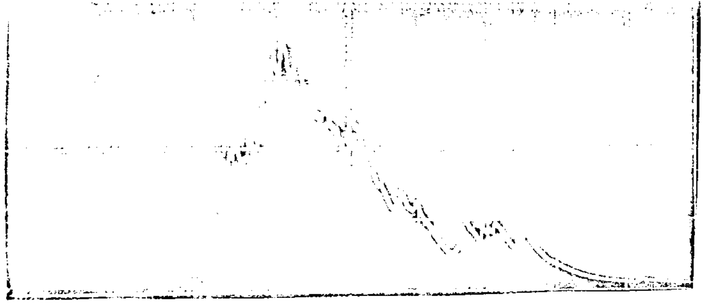
5KV Bank Voltage set to 4KV
Vert. 2V/cm
Horiz. 0.5msec/cm



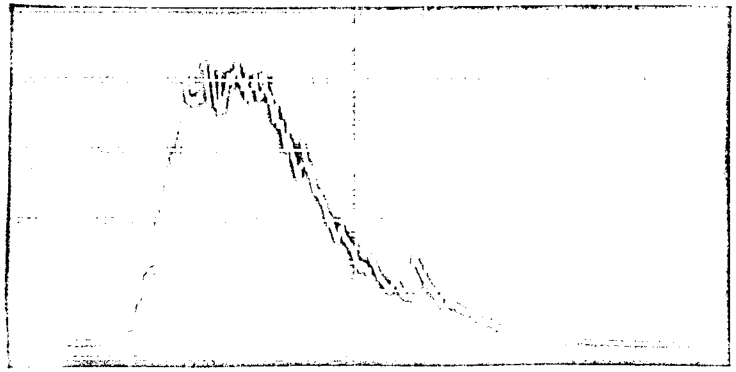
5KV Bank Voltage set to 3.7KV
Vert. 2V/cm
Horiz. 0.5msec/cm

Conventional Lasing Producing
"Coarse" Mode for Gyro Balancing.

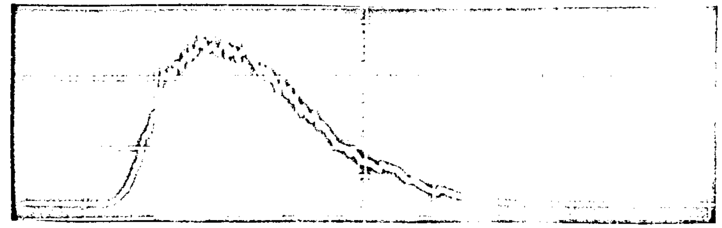
Figure 3



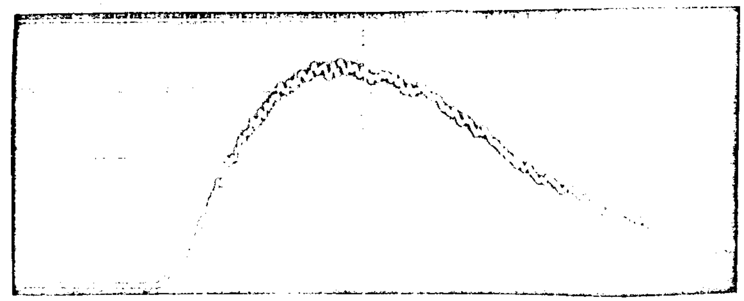
5KV Bank Voltage
Vert. .05V/cm
Horiz. 20μsec/cm



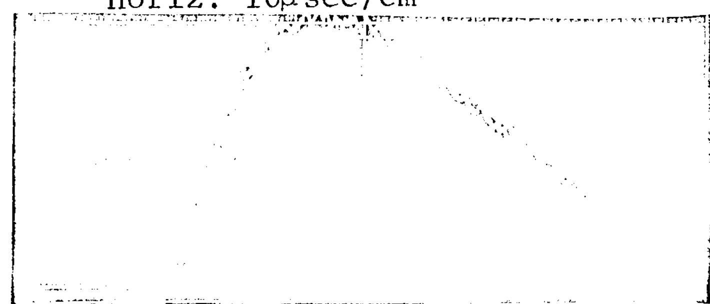
7KV Bank Voltage
Vert. 0.2V/cm
Horiz. 20μsec/cm



10KV Bank Voltage
Vert. 0.5V/cm
Horiz. 20μsec/cm



12KV Bank Voltage
Vert. 0.5V/cm
Horiz. 10μsec/cm

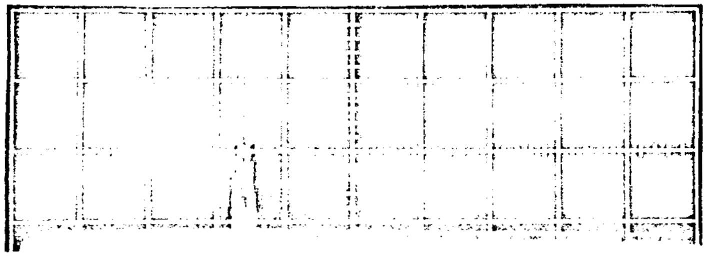


15KV Bank Voltage
Vert. 0.5V/cm
Horiz. 10μsec/cm

Laser Output Power Pulse for
Various 15KV Bank Voltages.

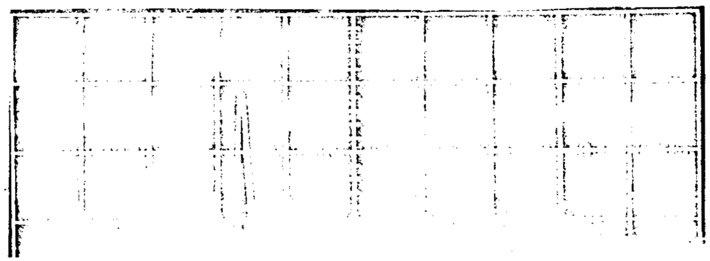
Figure 4

A



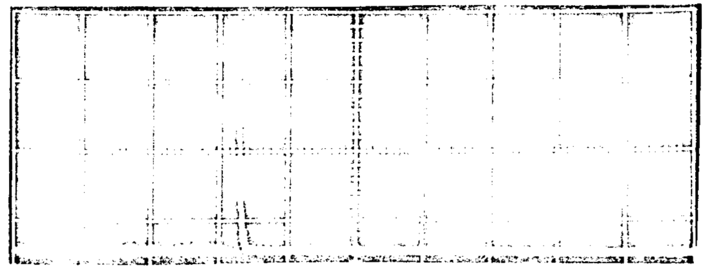
Laser Threshold reached at 5KV
Bank Voltage of 3.2KV
Vert. 0.1V/cm
Horiz. 0.5msec/cm

B



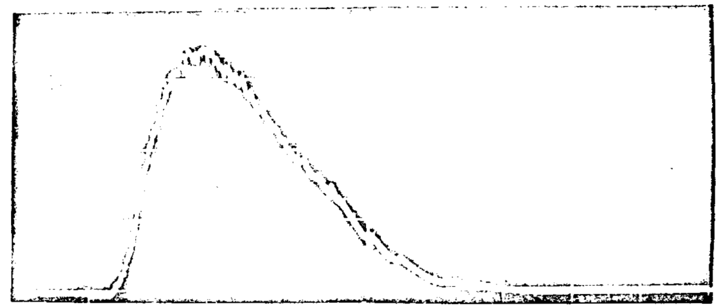
Piggy-back delay circuit adjusted to trigger at onset of lasing.
Vert. 10V/cm
Horiz. 0.5msec/cm

C



15KV Bank Voltage is discharged producing piggy-back laser pulse.
Vert. 5V/cm
Horiz. 0.5msec/cm

D



Piggy-back laser pulse, expanded time scale.
Vert. 5V/cm
Horiz. 20μsec/cm

Piggy-back or Hair Trigger Sequence
Producing "Fine" Mode for Gyro Balancing.

Figure 5

5.0 Conclusions

A laser system has been designed and built to dynamically balance gyro rotors and statically balance accelerometers.

The methods and procedures to optimize the use of the laser, to this end, will best be developed by the user as familiarity with the system is acquired.